DESCRIPTION

REGENERATION CONTROLLER FOR EXHAUST PURIFICATION APPARATUS
OF INTERNAL COMBUSTION ENGINE

TECHNICAL FIELD

The present invention relates to a regeneration
controller for an exhaust purification apparatus of an
internal combustion engine that eliminates particulate matter
trapped in the exhaust purification apparatus by heating the
exhaust purification apparatus.

BACKGROUND ART

Japanese Laid-Open Patent Publication No. 2003-20930
describes a technique for burning particulate matter (PM)
accumulated in a filter, which is arranged in an exhaust
passage of a diesel engine, when the amount of PM accumulated
in the filter exceeds a predetermined amount. The PM
accumulated in the filter is burned by heating the filter and
intermittently adjusting the air-fuel ratio to the lean side.
In this prior art, the amount of PM accumulated in the filter
is estimated by cyclically adding the amount of PM emitted
from the engine and the amount of PM oxidized in the filter
based on the driving state of the engine.

When the engine driving state is changing, the actual PM
emission amount and the PM oxidation amount may not be the
same and differ from each other. In particular, the
estimated PM accumulation amount may be less than the actual
PM accumulation amount. When the actual accumulation amount
is greater than the estimated accumulation amount, the
elimination of the accumulated PM may be insufficient. If

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such insufficient elimination is repeated, an excessively
large amount of PM may be accumulated. In such a case, a
greater amount of PM than intended may be rapidly burned. As
a result, the filter would become overheated. This would
cause thermal deterioration of the filter.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a
controller that minimizes the difference between the
estimated accumulation amount and the actual accumulation
amount of particulate matter, while appropriately eliminating
the particulate matter accumulated in an exhaust purification
apparatus.

One aspect of the present invention is a regeneration
controller for regenerating an exhaust purification apparatus
that is arranged in an exhaust passage for an internal
combustion engine. The exhaust purification apparatus
includes an upstream purification portion and a downstream
purification portion. The regeneration controller includes
difference detector for detecting at least one of a
difference in exhaust pressure, between a first location
upstream from the exhaust purification apparatus and a second
location downstream from the exhaust purification apparatus,
and a difference in exhaust temperature, between a third
location upstream from the downstream purification portion of
the exhaust purification apparatus and a fourth location
downstream from the third location. A calculation section
calculates an estimated accumulation amount of particulate
matter in the exhaust purification apparatus. A heating
control section heats the exhaust purification apparatus to
eliminate the particulate matter from the exhaust
purification apparatus when the estimated accumulation amount

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is greater than a reference accumulation amount. A
correction control section corrects the estimated
accumulation amount in accordance with the at least one
difference, when the estimated accumulation amount falls
within a correction determination reference range due to the
heating and the at least one difference is greater than a
correction reference value.

Another object of the present invention is a
regeneration controller for regenerating an exhaust
purification apparatus that is arranged in an exhaust passage
for an internal combustion engine. The exhaust purification
apparatus includes an upstream purification mechanism and a
downstream purification mechanism that are arranged in the
exhaust passage. The regeneration controller includes a
difference detector for detecting at least one of a
difference in exhaust pressure and a difference in exhaust
temperature between an upstream location and a downstream
location of the downstream purification mechanism. A
calculation section calculates an estimated accumulation
amount of particulate matter in the exhaust purification
apparatus. A heating control section heats the exhaust
purification apparatus to eliminate the particulate matter
from the exhaust purification apparatus when the estimated
accumulation amount is greater than a reference accumulation
amount. A correction control section corrects the estimated
accumulation amount, when the estimated accumulation amount
falls within a correction determination reference range due
to the heating and the at least one difference is greater
than a correction reference value, in accordance with the at
least one difference.

Other aspects and advantages of the present invention
will become apparent from the following description, taken in

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conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

Fig. 1 is a schematic diagram of a control system for a vehicle diesel engine according to a first embodiment of the present invention;

Fig. 2 is a flowchart of a regeneration mode execution determination executed by the ECU shown in Fig. 1;

Fig. 3 is a flowchart of regeneration control executed by the ECU shown in Fig. 1;

Fig. 4 shows a correction reference value map MAPdp;

Fig. 5 shows an addition correction amount map MAPadd;

Figs. 6 and 7 are timing charts of the regeneration control in the first embodiment;

Fig. 8 is a flowchart of regeneration control according to a second embodiment of the present invention;

Fig. 9 shows an addition correction amount map MAPtad;

Figs. 10 and 11 are flowcharts of regeneration control according to a third embodiment of the present invention; and

Fig. 12 is a schematic diagram of an exhaust purification apparatus according to a third embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

A regeneration controller for an exhaust purification apparatus of an internal combustion engine according to a first embodiment of the present invention will now be

discussed. Fig. 1 is a schematic diagram of a control system
including the regeneration controller, which is applied to a
vehicle diesel engine. The application of the regeneration
controller of the present invention is not limited to a
diesel engine. That is, the regeneration controller of the
present invention is also applicable to a lean-burn gasoline
engine.

A diesel engine 2 includes a plurality of cylinders
including first to fourth cylinders #1, #2, #3, and #4. In
each of the cylinders #1 to #4, a combustion chamber 4 is
connected to a surge tank 12 via an intake port 8 and an
intake manifold 10. Each intake port 8 is opened and closed
by an intake valve 6. The surge tank 12 is connected to an
intercooler 14 and a supercharger such as an exhaust
turbocharger 16. Fresh air supplied via an air cleaner 18 is
compressed by a compressor 16a of the exhaust turbocharger
16. The surge tank 12 has an EGR gas supply port 20a of an
exhaust gas recirculation (EGR) passage 20. A throttle valve
22 is arranged in an intake passage 13 between the surge tank
12 and the intercooler 14. An intake air amount sensor 24
(intake air amount detector) and an intake air temperature
sensor 26 are arranged between the compressor 16a and the air
cleaner 18.

In each of the cylinders #1 to #4, the combustion
chamber 4 is connected to an exhaust port 30 and an exhaust
manifold 32. Each exhaust port 30 is opened and closed by an
exhaust valve 28. An exhaust turbine 16b of the exhaust
turbocharger 16 is arranged between the exhaust manifold 32
and the exhaust passage 34. The exhaust is sent into the
exhaust turbine 16b from a position in the exhaust manifold
32 close to the fourth cylinder #4.

Three exhaust purification mechanisms, each
accommodating an exhaust purification catalyst, namely,
catalytic converters 36, 38, and 40, are arranged in the
exhaust passage 34. The first catalytic converter 36, which
is positioned the furthest upstream, accommodates a NOx
storage reduction catalyst 36a. When the exhaust of the
diesel engine 2, which is operating normally, is in an
oxidation atmosphere (lean), NOx is stored in the NOx storage
reduction catalyst 36a. When the exhaust is in a reduction
atmosphere (stoichiometric or air-fuel ratio being lower than
that the stoichiometric condition), the NOx stored in the NOx
storage reduction catalyst 36a is reduced to NO, separated
from the NOx storage reduction catalyst 26a, and further
reduced using HC and CO. In this way, NOx is eliminated.

The second catalytic converter 38, which is arranged
downstream from the first catalytic converter 36,
accommodates a filter 38a having a monolithic structure.
Walls of the filter 38a have pores that permit the passage of
exhaust. The porous wall surface of the filter 38a is coated
with a layer of a NOx storage reduction catalyst. The filter
38a functions as a base for the NOx storage reduction
catalyst layer. The NOx storage reduction catalyst layer
eliminates NOx in the same manner as the NOx storage
reduction catalyst 36a. Particulate matter (PM) contained in
the exhaust is accumulated in the wall of the filter 38a.
The PM is first oxidized by active oxygen released when NOx
is exposed in an oxidation atmosphere under a relatively high
temperature. Then, the PM is entirely oxidized by the
surrounding excess oxygen. In this way, not only NOx but
also PM is eliminated from the filter 38a. The first
catalytic converter 36 is formed integrally with the second
catalytic converter 38.

The third catalytic converter 40, which is positioned most downstream, accommodates an oxidation catalyst 40a for eliminating HC and CO through oxidation. A first exhaust temperature sensor 44 is arranged between the NOx storage reduction catalyst 36a and the filter 38a. Between the filter 38a and the oxidation catalyst 40a, a second exhaust temperature sensor 46 is arranged near the filter 38a, and an air-fuel ratio sensor 48 is arranged near the oxidation catalyst 40a.

The air-fuel ratio sensor 48 is, for example, a sensor using a solid electrolyte. The air-fuel ratio sensor 48 detects the air-fuel ratio of the exhaust based on exhaust components and generates a voltage signal, which is linearly proportional to the air-fuel ratio. The first exhaust temperature sensor 44 and the second exhaust temperature sensor 46 respectively detect exhaust temperatures thci and thco at their respective locations.

A pressure difference sensor 50 is connected to a pipe connecting the upstream side and downstream side of the filter 38a. The pressure difference sensor 50 detects the pressure difference ΔP between the upstream and downstream sides of the filter 38a to detect the clogging degree of the filter 38a, that is, the degree of accumulation of PM in the filter 38a.

The exhaust manifold 32 has an EGR gas inlet 20b of the EGR passage 20 located near the first cylinder #1, or distant from the fourth cylinder #4 that sends exhaust into the exhaust turbine 16b. An iron EGR catalyst 52 for reforming the EGR gas, a cooler 54 for cooling the EGR gas, and an EGR valve 56 are arranged in the EGR passage 20 in this order from the EGR gas inlet 20b. The EGR catalyst 52 also

functions to prevent clogging of the cooler 54. The amount
of EGR gas that is to be supplied again to the intake system
via the EGR gas supply port 20a is adjusted according to the
opening degree of the EGR valve 56.

A fuel injection valve 58 is arranged in each of the
cylinders #1 to #4 and directly injects fuel into the
corresponding combustion chamber 4. Each fuel injection
valve 58 is connected to a common rail 60 via a fuel supply
pipe 58a. A variable discharge amount fuel pump 62, which is
electrically controlled, supplies high-pressure fuel into the
common rail 60. The high-pressure fuel in the common rail 60
is distributed to the corresponding fuel injection valve 58
via each fuel supply pipe 58a. A fuel pressure sensor 64
detects the pressure of fuel in the common rail 60.

The fuel pump 62 supplies low-pressure fuel to a fuel
adding valve 68 via a fuel supply pipe 66. The fuel adding
valve 68 is arranged in an exhaust port 30 of the fourth
cylinder #4 to inject fuel toward the exhaust turbine 16b.
The fuel adding valve 68 adds fuel to the exhaust in a
catalyst control mode.

An electronic control unit (ECU) 70 includes a digital
computer system including a CPU, a ROM, a RAM, and drive
circuits. The drive circuit drives various units. The ECU 70
is provided with detection signals from the intake air amount
sensor 24, the intake air temperature sensor 26, the first
exhaust temperature sensor 44, the second exhaust temperature
sensor 46, the air-fuel ratio sensor 48, the pressure
difference sensor 50, an EGR opening degree sensor included
in the EGR valve 56, a fuel pressure sensor 64, a throttle
opening degree sensor 22a, an accelerator opening degree
sensor 74, a coolant temperature sensor 76, an engine speed

sensor 80, and a cylinder distinction sensor 82. The
accelerator opening degree sensor 74 detects the depressed
amount of an accelerator pedal 72 (accelerator opening degree
ACCP). The coolant temperature sensor 76 detects the coolant
temperature THW of the diesel engine 2. The engine speed
sensor 80 detects the engine speed NE, or rotation speed of
the crankshaft 78. The cylinder distinction sensor 82
detects the rotational phase of the crankshaft 78 or the
rotational phase of an intake cam to distinguish cylinders.

The ECU 70 determines the driving state of the engine
from these detection signals to control fuel injection
(amount and timing) of the fuel injection valves 58 according
to the driving state of the engine. The ECU 70 executes
control for adjusting the opening degree of the EGR valve 56,
adjusting the throttle opening degree with a motor 22b, and
adjusting the discharge amount of the fuel pump 62. Further,
the ECU 70 executes catalyst control including a regeneration
mode, a sulfur components decomposition-release mode
(hereinafter referred as a sulfur elimination mode), a NOx
reduction mode, and a normal control mode. The catalyst
control will be described later.

The ECU 70 executes a combustion mode selected from two
combustion modes, namely, a normal combustion mode and a low
temperature combustion mode, according to the driving state
of the engine. In the low temperature combustion mode, the
ECU 70 simultaneously reduces NOx and smoke by slowing the
increase of the combustion temperature by using a large
recirculation amount of exhaust based on an EGR valve opening
degree map for the low temperature combustion mode. The low
temperature combustion mode is executed when the engine is in
a range in which the engine load is low and the engine speed
is low or intermediate. In the low temperature combustion

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mode, the ECU 70 executes air-fuel ratio feedback control
including adjustment of a throttle opening degree TA based on
the air-fuel ratio AF detected by the air-fuel ratio sensor
48. A combustion mode other than the low temperature
combustion mode is the normal combustion mode. In the normal
combustion mode, the ECU 70 executes normal EGR control
(including control that involves no recirculation of the
exhaust) based on an EGR valve opening degree map for the
normal combustion mode.

The catalyst control will now be described.

In the regeneration mode, the ECU 70 particularly heats
PM accumulated in the filter 38a of the second catalytic
converter 38 when the estimated accumulation amount of PM in
the exhaust purification catalyst reaches a regeneration
reference value. The PM is heated to be oxidized and
decomposed to generate CO_2 and H_2O and is released as CO_2 and
H_2O. In the regeneration mode, the ECU 70 repeatedly adds
fuel with the fuel adding valve 68 to heat (e.g., 600 to
700°C) the catalyst bed at an air-fuel ratio that is higher
than the stoichiometric air-fuel ratio. The ECU 70 may
further perform fuel injection (after injection) in each
combustion chamber 4 with the corresponding fuel injection
valve 58 during the power stroke or the exhaust stroke. The
ECU 70 further executes burn-up heating by executing an
intermittent fuel adding process under a specific condition,
which will be described later. In the intermittent fuel
adding process, the ECU 70 executes an air-fuel ratio
lowering process between periods in which no fuel is added.
The air-fuel ratio lowering process lowers the air-fuel ratio
to be the same as or slightly lower than the stoichiometric
air-fuel ratio by intermittently adding fuel from the fuel
adding valve 68. In this embodiment, the air-fuel ratio

lowering process causes the air-fuel ratio to be slightly
lower than the stoichiometric air-fuel ratio. In certain
cases, the after injection with the fuel injection valves 58
and the intermittent fuel adding process may be performed in
combination. In the regeneration mode, the PM clogging at
the front surface of the NOx storage reduction catalyst 36a
is eliminated and the PM accumulated in the filter 38a at an
accumulation amount greater than the estimated accumulation
amount is burned and reduced.

The sulfur elimination mode is executed when the NOx
storage reduction catalyst 36a and the filter 38a are
poisoned by sulfur components and their exhaust purification
capacity such as NOx storage capacity is lowered. The sulfur
elimination mode decomposes and releases sulfur components
from the NOx storage reduction catalyst 36a and the filter
38a so that the NOx storage reduction catalyst 36a and the
filter 38a are rid of sulfur components and restored from
sulfur poisoning. In the sulfur elimination mode, the ECU 70
heats the catalyst bed (e.g., to 650°C) by repeatedly adding
fuel from the fuel adding valve 68. The ECU 70 further
executes an air-fuel ratio lowering process that lowers the
air-fuel ratio to be the same as or slightly lower than the
stoichiometric air-fuel ratio by intermittently adding fuel
from the fuel adding valve 68. In the first embodiment, the
air-fuel ratio lowering process causes the air-fuel ratio to
be slightly lower than the stoichiometric air-fuel ratio. In
the sulfur elimination mode, the after injection using the
fuel injection valve 58 may also be executed. This process
is similar to the intermittent fuel adding process executed
under a specific condition in the regeneration mode and also
has the effect of burning up the PM.

In the NOx reduction mode, NOx occluded in the NOx

storage reduction catalyst 36a and the filter 38a is reduced to N_2, CO_2, and H_2O, and is released as N_2, CO_2, and H_2O. In the NOx reduction mode, the ECU 70 intermittently adds fuel from the fuel adding valve 68 at relatively long time intervals so that the temperature of the catalyst bed is set relatively low (e.g., 250 to 500°C). At such a relatively low catalyst bed temperature, the air-fuel ratio is lowered to be the same as or slightly lower than the stoichiometric air-fuel ratio.

The catalyst control excluding the three catalyst control modes described above is the normal control mode. In the normal control mode, the ECU 70 does not perform the fuel addition with the fuel adding valve 68 and the after injection with the fuel injection valve 58.

The processing executed by the ECU 70 in the regeneration mode will now be discussed. The flowchart of Fig. 2 showing the regeneration mode execution determination and the flowchart of Fig. 3 showing the regeneration control are each executed as interrupts in predetermined time cycles. The result of the regeneration mode execution determination in Fig. 2 determines whether to start the regeneration control in Fig. 3.

The regeneration mode execution determination (Fig. 2) will first be described.

In step S102, the ECU 70 calculates the particulate matter emission amount PMe, which is the total amount of PM emitted from each combustion chamber 4 of the diesel engine 2 during one control cycle in Fig. 2. In this embodiment, the ECU 70 calculates the particulate matter emission amount PMe by referring to a map, which is generated in advance through

experiments. The map associates the emission amount with,
for example, the engine speed NE and with the engine load
(e.g., the fuel injection amount of the fuel injection valve
58). The ECU 70 calculates the particulate matter emission
amount PMe from the engine speed NE and the engine load.

In step S104, the ECU 70 calculates the oxidation amount
PMc of PM that is accumulated or trapped in the filter 38a.
The oxidation amount PMc is the amount of the trapped PM that
is eliminated through oxidation during one control cycle of
this process. In the first embodiment, the ECU 70 calculates
the oxidation amount PMc by referring to a map, which is
generated in advance through experiments. The map associates
the oxidation amount with the catalyst bed temperature of the
filter 38a (e.g., the exhaust temperature thco detected by
the second exhaust temperature sensor 46) and with an intake
air amount GA. The ECU 70 calculates the oxidation amount
PMc from the exhaust temperature thco and the intake air
amount GA.

In step S106, the ECU 70 calculates an estimated PM
accumulation amount PMsm using expression 1.

$$PMsm \leftarrow Max[PMsm+PMe-PMc, 0] \qquad (1)$$

In expression 1, the estimated accumulation amount PMsm
in the right side is the value calculated in the previous
cycle of this process. Max represents an operator for
extracting the maximum value of the values in the
parentheses. For example, when PMsm+PMe-PMc is a positive
value, the resulting value of PMsm+PMe-PMc is entered as the
estimated accumulation amount PMsm at the left side of the
expression. When PMsm+PMe-PMc is a negative value, zero
(grams) is entered as the estimated accumulation amount PMsm

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at the left side of the expression.

In step S108, the ECU 70 checks whether the estimated accumulation amount PMsm is greater than or equal to a regeneration reference value PMstart (corresponding to a reference accumulation amount) and determines whether to start the regeneration mode. When PMsm is less than PMstart (NO in step S108), the ECU 70 temporarily terminates this process. The state in which PMsm is less than PMstart corresponds to a state before timing t0 shown in the timing chart of Fig. 6.

When the state in which PMe is greater than PMc continues due to the driving state of the diesel engine 2, steps S102, S104, and S106 is repeated. This gradually increases the estimated accumulation amount PMsm. However, as long as PMsm is less than PMstart (NO in step S108), the ECU 70 temporarily terminates this process.

When the estimated accumulation amount PMsm increases and satisfies PMsm ≥ PMstart (YES in step S108), the ECU 70 determines whether heating for PM elimination in the sulfur elimination mode has stopped. When the PM elimination heating in the sulfur elimination mode has stopped (NO in step S110), the ECU 70 temporarily terminates this process. When the PM elimination heating in the sulfur elimination mode is being performed (YES in step S110), the ECU 70 starts the regeneration control (step S112, t0 in Fig. 6). In this case, the regeneration control shown in Fig. 3 is executed cyclically.

The regeneration control will now be described with reference to Fig. 3. The ECU 70 executes the regeneration control after executing the regeneration mode execution

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determination in Fig. 2. Thus, the regeneration control is executed in the same cycle as the regeneration mode execution determination.

In step S122, the ECU 70 determines whether the estimated accumulation amount PMsm calculated in the previous cycle is within a correction determination reference range (less than or equal to a maximum value BUpm of the correction determination reference range). As shown in Fig. 6, the maximum value BUpm is much smaller than the regeneration reference value PMstart and slightly greater than a termination determination value PMend (e.g., 0 grams).

When PMsm is greater than BUpm (NO in step S122, t0 to t1 in Fig. 6), the ECU 70 sets (instructs) initiation of the PM elimination heating in step S146 and temporarily terminates this process. In the PM elimination heating, the fuel adding valve 68 repeatedly adds fuel in the manner described above. This exposes the catalyst to an atmosphere in which the air-fuel ratio is higher than the stoichiometric air-fuel ratio and raises the catalyst bed temperature (exhaust temperature thci) (e.g., 600 to 700°C). Then, the particulate matter emission amount PMe becomes less than the oxidation amount PMc, and the estimated accumulation amount PMsm decreases gradually.

As long as PMsm is greater than BUpm (NO in step S122), the process for eliminating PM by the fuel addition described above is continued.

The estimated accumulation amount PMsm gradually decreases and approaches the termination determination value PMend. When the estimated accumulation amount PMsm decreases and satisfies PMsm ≤ BUpm (YES in step S122), the ECU 70

determines whether a mode other than the sulfur elimination
mode is presently being executed and whether a mode other
than the sulfur elimination mode has been requested (step
S124).

When the sulfur elimination mode is being executed or
when the sulfur elimination mode has been requested (NO in
step S124), the ECU 70 stops the PM elimination heating (step
S138) and temporarily terminates this process. The PM
elimination heating is stopped because a processing similar
to the burn-up heating is performed in the sulfur elimination
mode.

When a mode other than the sulfur elimination mode is
being executed and the sulfur elimination mode is not
requested (YES in step S124), the ECU 70 refers to a
correction reference value map MAPdp shown in Fig. 4 and
determines a correction reference value Dp that corresponds
to the intake air amount GA (step S126). The ECU 70
determines whether the ratio $\Delta P/GA$ of the pressure difference
ΔP between the upstream and downstream sides of the filter
38a to the intake air amount GA is greater than or equal to a
correction reference value Dp (step S128). The ratio $\Delta P/GA$
corresponds to an exhaust pressure difference. Accordingly,
the reference value Dp is used as a minimum value of the
ratio $\Delta P/GA$. The accuracy for determining clogging of the
filter 38a is ensured by determining the reference value Dp.

It is preferred that the ratio of the pressure
difference ΔP to an exhaust flow amount be used instead of
the ratio $\Delta P/GA$ to accurately reflect the actual driving
state. However, the intake air amount GA is directly
proportional to the exhaust flow amount. Thus, the use of
the ratio $\Delta P/GA$ does not affect control accuracy.

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Instead of comparing the ratio $\Delta P/GA$ with the value Dp, the pressure difference ΔP may be compared with a correction reference value (e.g., Dp*GA) that is set larger in accordance with the exhaust flow amount (or the intake air amount GA). In this case, the pressure difference ΔP corresponds to the exhaust pressure difference.

When $\Delta P/GA$ is less than Dp (NO in step S128), the filter 38a is not clogged with PM, and the estimated accumulation amount PMsm is not deviated from the actual accumulation amount. In this case, the ECU 70 determines whether the estimated accumulation amount PMsm is less than or equal to the termination determination value PMend in step S140. In the initial stage of the regeneration control, PMsm is less than PMend (NO in step S140). Thus, the PM elimination heating is continued (step S146). In this case, as shown in Fig. 6, the estimated accumulation amount PMsm continues to degrease gradually after timing t1 in accordance with the calculation using the expression 1.

When the state in which $\Delta P/GA$ is less than Dp continues (NO in step S128) and the estimated accumulation amount PMsm decreases and satisfies PMsm $\leq$ PMend (0 grams) (YES in step S140, t2 in Fig. 6), the ECU 70 stops the PM elimination heating (step S142) and ends the regeneration mode (step S144). Then, the ECU 70 temporarily terminates this process. This completes the elimination of PM mainly trapped in the filter 38a. When the estimated accumulation amount PMsm increases to satisfy PMsm $\geq$ PMstart again (YES in step S108 of Fig. 2), the regeneration control is started again in the manner described above (step S112) unless the regeneration control is stopped by the sulfur elimination mode (YES in step S110).

The following describes a case in which the filter 38a is clogged with PM and the estimated accumulation amount PMsm is deviated from the actual accumulation amount. In this case, the ratio $\Delta P/GA$ becomes greater than or equal to the correction reference value Dp (YES in step S128) after the determination in step S122 results in YES and the determination in step S124 results in YES.

In step S130, the ECU 70 determines whether the number of times the determination in step S128 results in YES, that is, the number of times the ratio $\Delta P/GA$ is consecutively determined as greater than or equal to the value Dp is less than or equal to a stop determination number Np (e.g., two). For example, when the determination number is smaller than the stop determination number Np such as when the determination in step S130 has been executed for the first time (YES in step S130), the ECU 70 refers to an addition correction amount map MAPadd shown in Fig. 5 and determines an increase correction amount PMadd corresponding to the ratio $\Delta P/GA$ (step S132).

The ratio $\Delta P/GA$ reflects the deviation of the estimated accumulation amount PMsm from the actual accumulation amount. The addition correction map MAPadd shows addition correction amounts PMadd in correspondence with the ratio $\Delta P/GA$, or in accordance with the above-mentioned deviation. The relationship between the ratio $\Delta P/GA$ and the addition correction amount PMadd is determined through experiments.

The ECU 70 obtains or corrects the estimated accumulation amount PMsm using expression (2).

$$PMsm \leftarrow PMsm + PMadd \qquad (2)$$

In this case, the estimated accumulation amount PMsm is increased to a value close to or equal to the actual accumulation amount (t11).

In step S136, the ECU 70 switches from the PM elimination heating to the burn-up heating and temporarily terminates this process. When burn-up heating is started, the PM clogging at the front surface of the NOx storage reduction catalyst 36a is eliminated, and the amount of PM accumulated in the filter 38a that is greater than the estimated accumulation amount PMsm is burned up. This reduces the deviation of the estimated accumulation amount PMsm from the actual accumulation amount. The estimated accumulation amount PMsm is once lowered to be less than or equal to the maximum value BUpm, which is slightly greater than the termination determination value PMend. Thus, even if the estimated accumulation amount PMsm deviates from the actual accumulation amount, the burn-up heating avoids a case in which a large amount of PM is burned rapidly.

In a period in which PMsm is greater than BUpm (NO in step S122), the burn-up type PM elimination heating is performed (step S146). When PMsm $\leq$ BUpm is satisfied again (YES in step S122, t12 in Fig. 7) and $\Delta P/GA$ is less than Dp (NO in step S128) and PMsm is greater than PMend (NO in step S140), the PM elimination heating is continued as indicated by the solid line in Fig. 7 (step S146). When PMsm $\leq$ PMend is satisfied (YES in step S140), the PM elimination heating is stopped (step S142), and the regeneration mode is completed (step S144, t13 in Fig. 7).

When $\Delta P/GA \geq$ Dp is satisfied (YES in step S128), the ECU 70 determines whether the determination number in step S128 is less than or equal to the stop determination number Np

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(two) (step S130). For example, when the determination in step S128 is executed for the second time (YES in step S130), the ECU 70 determines again the addition correction amount PMadd based on the ratio $\Delta P/GA$ (step S132) and corrects the estimated accumulation amount PMsm with the updated addition correction amount PMadd (step S134). Thus, as indicated by the broken line in Fig. 7, the estimated accumulation amount PMsm increases again to a value greater than the maximum value BUpm (t12).

The ECU 70 continues the burn-up heating (step S136), and temporarily terminates this process. The continued burn-up heating further reduces the deviation of the estimated accumulation amount PMsm from the actual accumulation amount.

In a period in which PMsm is greater than BUpm (NO in step S122), the ECU 70 continues the burn-up heating (step S146). When $PMsm \geq BUpm$ is satisfied again (YES in step S122, t14 in Fig. 7), and when $\Delta P/GA$ is less than Dp (NO in step S128) and PMsm is greater than PMend (NO in step S140), the ECU 70 continues the burn-up type PM elimination heating (step S146). When $PMsm \leq PMend$ is satisfied (YES in step S140, t15 in Fig. 7), the ECU 70 stops the PM elimination heating (step S142) and completes the regeneration mode (step S144).

When $\Delta P/GA \geq Dp$ is satisfied (YES in step S128, t13), the determination relating to the ratio $\Delta P/GA$ has been executed for the third time (NO in step S130). In this case, the ECU 70 executes the same processing as the processing executed when $\Delta P/GA$ is less than Dp. When $PMsm \leq PMend$ is satisfied as indicated by the broken line in Fig. 7 (YES in step S140, t15 in Fig. 7), the ECU 70 stops the PM elimination heating (step S142), and completes the

regeneration mode (step S144).

The pressure difference sensor 50 and the intake air amount sensor 24 serve as a difference detector. The ECU 70 executing steps S122 to S134 functions as a correction control section for the estimated accumulation amount.

The first embodiment has the advantages described below.

(a) The flow resistance of the exhaust increases and the exhaust pressure difference ΔP/GA between the upstream and downstream sides of the filter 38a increases as the degree of the PM clogging in the filter 38a in the second catalytic converter 38 increases. When the estimated accumulation amount PMsm does not deviate from the actual accumulation amount, the exhaust pressure difference ΔP/GA corresponds to the estimated accumulation amount PMsm. Accordingly, the estimated accumulation amount PMsm is accurate if the exhaust pressure difference ΔP/GA detected by the pressure difference sensor 50 is a value corresponding to the correction determination reference range (≤ BUpm) when the estimated accumulation amount PMsm falls within the correction determination reference range.

When the exhaust pressure difference ΔP/GA is greater than the correction determination reference range, the actual accumulation amount is greater than the estimated accumulation amount PMsm. If such state continues, the regeneration mode is completed even though there is residual PM. When such residual PM elimination is accumulated, the deviation of the estimated accumulation amount PMsm from the actual accumulation amount gradually increases. This would lead to an amount of PM greater than intended to be burned rapidly. As a result, the filter 38a may become excessively

heated and cause thermal deterioration of the filter 38a.

In the first embodiment, the ECU 70 compares the ratio $\Delta P/GA$ with the correction reference value Dp when $PMsm \leq BUpm$ is satisfied to determine whether the estimated accumulation amount PMsm is deviated from the actual accumulation amount. When $\Delta P/GA \geq Dp$ is satisfied, the ECU 70 refers to the addition correction amount map MAPadd to determine the addition correction amount PMadd corresponding to the ratio $\Delta P/GA$ and corrects the estimated accumulation amount PMsm with the addition correction amount PMadd. As the ratio $\Delta P/GA$ increases, the addition correction amount PMadd increases. This causes the estimated accumulation amount PMsm to approach or be the same as the actual accumulation amount.

In this way, the difference between the estimated accumulation amount PMsm and the actual accumulation amount is minimized so that the PM accumulated in the filter 38a is appropriately eliminated. This prevents a large amount of PM from being rapidly burned.

(b) Normally, in accordance with the flow amount of exhaust, the flow uniformity of the exhaust flow changes and the accuracy of sensors for detecting exhaust pressure and exhaust temperature decreases. Therefore, it is preferable that the correction reference value be set in accordance with the exhaust flow amount. In the first embodiment, the ECU 70 refers to the correction reference map MAPdp shown in Fig. 4 to determine the correction reference value Dp. The correction reference value Dp in the correction reference value map MAPdp is set so that it becomes smaller as the intake air amount GA increases. As the intake air amount GA increases, the exhaust flow amount increases. This improves

the flow uniformity of the exhaust flow amount. Thus, the correction reference value Dp decreases as the intake air amount GA increases, and the correction reference value Dp increases as the intake air amount GA decreases. This determines the timing for correcting the estimated accumulation amount PMsm with high accuracy and thus obtains an addition correction amount PMadd with higher accuracy. Accordingly, the estimated accumulation amount PMsm is corrected with higher accuracy, and the deviation of the estimated accumulation amount PMsm from the actual accumulation amount is minimized with further accuracy.

(c) The intake air amount GA detected by the intake air amount sensor 24 is used in lieu of the exhaust flow amount. Thus, the appropriate correction reference value Dp is easily set, and a highly accurate addition correction amount PMadd is easily obtained at a highly accurate timing.

(d) The correction determination reference range defined using the maximum value BUpm is set in a range defined by the estimated accumulation amount PMsm immediately before the regeneration mode is completed. The actual PM accumulation amount is sufficiently reduced by executing normal heating for PM elimination. Thus, even when burn-up heating is performed to burn up all of the PM at the same time, a state in which the burn-up heating rapidly burns a large amount of PM is avoided. Thus, even with such special heating, the filter 38a is not excessively heated and thermal deterioration of the filter 38a does not occur. Hence, the accumulated particulate matter is appropriately eliminated.

(e) When the corrected estimated accumulation amount PMsm falls within the correction determination reference range again and $\Delta P/GA \geq Dp$ is satisfied, the ECU 70 repeats

the correction of the estimated accumulation amount PMsm. Thus, even when compensation for the deviation of the estimated accumulation amount PMsm in the previous cycle from the actual accumulation amount is insufficient, repeated correction of the estimated accumulation amount PMsm almost completely eliminates the deviation of the estimated accumulation amount PMsm from the actual accumulation amount.

(f) The presence of non-combustible materials, such as ash, may cause a state in which $\Delta P/GA \geq Dp$ is satisfied to continue. In this case, repeatedly correcting the estimated accumulation amount PMsm to extend the regeneration mode may lower fuel efficiency. Thus, the ECU 70 limits the number of times the estimated accumulation amount PMsm is corrected to prevent the fuel efficiency from decreasing. In this embodiment, the stop determination number Np is set as two so that the correction of the estimated accumulation amount PMsm is not executed three consecutive times.

(g) The sulfur elimination mode has the same effect as the effect of the burn-up heating. Thus, even when the estimated accumulation amount PMsm deviates from the actual accumulation amount, the deviation is reduced or eliminated in the sulfur elimination mode. Thus, the ECU 70 does not execute the correction of the estimated accumulation amount PMsm in the sulfur elimination mode. In this way, the regeneration mode, particularly the burn-up heating, is not often executed to prevent the fuel efficiency from decreasing.

Regeneration control for an exhaust purification apparatus of an internal combustion engine according to a second embodiment of the present invention will now be described with reference to Fig. 8.

In the second embodiment, the exhaust temperature
difference ΔTHC (thco-thci) between the upstream and
downstream sides of the filter 38a, which corresponds to a
downstream exhaust purification mechanism, is used in lieu of
the exhaust pressure difference ΔP/GA. That is, the ECU 70
determines whether ΔTHC is greater than or equal to the
correction reference value Dth. The correction reference
value Dth is a value between, for example, 200 to 300°C.
Steps S125, S127, S129, and S131 of Fig. 8 respectively
replace steps S126, S128, S130, and S132 of Fig. 3. The
other parts are the same as the first embodiment.

When the determination of step S124 results in YES, the
ECU 70 obtains the exhaust temperature difference ΔTHC in
accordance with expression 3.

$$\Delta THC \leftarrow thco - thci \qquad (3)$$

The ECU 70 determines whether the exhaust temperature
difference ΔTHC is greater than or equal to the correction
reference value Dth (step S127). When ΔTHC is less than Dth
(NO in step S127) and PMsm is greater than PMend (NO in step
S140), the ECU 70 continues the PM elimination heating (step
S146). When PMsm ≤ PMend is satisfied (YES in step S140),
the ECU 70 stops PM elimination heating (step S142) and ends
the PM regeneration control mode (step S144). During these
steps, PMsm changes as shown by the timing chart of Fig. 6.

When ΔTHC ≥ Dth is satisfied (YES in step S127), the ECU
70 checks whether the number of times the determination of
step S127 resulted in YES during repeating the present PM
elimination heating is less than or equal to a stop
determination number Np (e.g., two) (step S129). For
example, when step S127 is performed the first time, the ECU

70 determines the result of S129 as YES. In this case, the ECU 70 refers to the addition correction amount map MAPtad shown in Fig. 9 to determine the addition correction amount PMaad corresponding to the exhaust temperature difference ΔTHC (step S131).

When clogging of the front surface of the NOx storage reduction catalyst 36a deviates the estimated accumulation amount PMsm from the actual accumulation amount, the fuel added by the fuel adding valve 68 to perform PM elimination heating is hardly burned when passing through the NOx storage reduction catalyst 36a and burned in a concentrated manner at the filter 38a. This increases the exhaust temperature difference ΔTHC in comparison to when the front surface of the NOx storage reduction catalyst 36a is not clogged. In other words, the exhaust temperature difference ΔTHC reflects the deviation of the estimated accumulation amount PMsm from the actual accumulation amount that is caused by the clogging of the front surface of the NOx storage reduction catalyst 36a. The addition correction amount map MAPtad stores the addition correction amount PMadd corresponding to the exhaust temperature difference ΔTHC. The level of deviation becomes greater as the exhaust temperature difference ΔTHC increases. Thus, the addition correction amount PMadd increases as the exhaust temperature difference ΔTHC increases. The association of the exhaust temperature difference ΔTHC with the addition correction amount PMadd is obtained through experiments.

The ECU 70 uses the addition correction amount PMadd to correct the predicted accumulation amount PMsm in accordance with expression 2 (step S134). This increases the estimated accumulation amount PMsm to approach or become equal to the actual accumulation amount as shown in the timing chart of

Fig. 7.

The ECU 70 switches from PM elimination heating to burn-
up heating (step S136). Even if the estimated accumulation
amount PMsm is deviated from the actual accumulation amount
when starting burn-up heating, the estimated accumulation
amount PMsm is less than or equal to the maximum value BUpm,
which is slightly greater than the termination determination
value PMend. Accordingly, even if burn-up heating is
performed, a large amount of PM is not rapidly burned. Thus,
the filter 38a is not overheated.

During the period in which PMsm is greater than BUpm (NO
in step S122), the ECU 70 eliminates PM by performing burn-up
heating (step S146). When PMsm ≤ BUpm is satisfied again
(YES in step S122) and the determination of step S124 is YES,
the ECU 70 calculates the exhaust temperature difference ΔTHC
(step S125). If ΔTHC is less than the correction reference
value Dth (NO in step S127) and PMsm is greater than PMend
(NO in step S140), the ECU 70 continues PM elimination
heating (step S146, solid line in Fig. 7). If PMsm ≤ PMend
is satisfied (YES in step S140), the ECU 70 stops PM
elimination heating (step S142) and ends the PM regeneration
control mode (step S144).

When ΔTHC ≥ Dth is satisfied again (YES in step S127),
the ECU 70 checks whether the number of times the
determination of step S127 results in YES is less than or
equal to the stop determination number Np (two) (step S129).
Since the present determination number is two, the ECU 70
calculates the addition correction amount PMadd again based
on ΔTHC (step S131), updates the addition correction amount
PMadd, and corrects the estimated accumulation amount PMsm
again with the updated addition correction amount PMadd (step

S134). As shown by the broken line in Fig. 7, this increases the estimated accumulation amount PMsm again to a value greater than the maximum value BUpm of the correction determination reference range.

The ECU 70 continues burn-up heating (step S136) and temporarily terminates this process. The continuation of burn-up heating further eliminates the deviation of the estimated accumulation amount PMsm and the actual accumulation amount.

During the period in which PMsm is greater than BUpm (NO in step S122), the ECU 70 continues burn-up heating (step S146). Even if PMsm $\leq$ BUpm is satisfied again (YES in step S122), as long as ΔTHC $\geq$ Dth is satisfied (YES in step S127), the ECU 70 determines the result of step S129 as NO. Even if ΔTHC $\geq$ Dth is satisfied or ΔTHC is less than Dth, the ECU 70 proceeds to step S140.

If burn-up heating continues and PMsm $\leq$ PMend is satisfied (YES in step S140), the ECU 70 stops PM elimination heating (step S142) and ends the PM regeneration control mode (step S144).

The first exhaust temperature sensor 44 and the second exhaust temperature sensor 46 serve as a difference detector. The ECU 70 executing steps S122 to S134 of Fig. 8 functions as a correction control section for correcting the estimated accumulation amount.

The second embodiment has the advantages described below.

(a) When the NOx storage reduction catalyst 36a

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(upstream exhaust purification mechanism) is clogged with PM before the filter 38a is clogged with PM, the exhaust passes through only a limited portion of the NOx storage reduction catalyst 36a during the regeneration control. Thus, the reaction heat of the NOx storage reduction catalyst 36a is insufficient, and reaction heat is unevenly generated in the downstream filter 38a.

Accordingly, in the second embodiment, the exhaust temperature difference thco-thci between the upstream and downstream sides of the filter 38a is used in lieu of the exhaust pressure difference ΔP/GA. The ECU 70 corrects the estimated accumulation amount PMsm when the temperature difference is greater than or equal to the correction reference value Dth. This causes the estimated accumulation amount PMsm to approach or to be the same as the actual accumulation amount.

In this way, the difference between the estimated accumulation amount PMsm and the actual accumulation amount is minimized so that the accumulated PM is appropriately eliminated. This prevents rapid burning of a large amount of PM.

(b) The second embodiment also has advantages (d) to (g) described in the first embodiment.

Regeneration control for an exhaust purification apparatus of an internal combustion engine according to a third embodiment of the present invention will now be discussed.

In the third embodiment, the flowcharts of Figs. 10 and 11 are performed in lieu of the flowchart of Fig. 3. The

flowcharts of Figs. 10 and 11 are obtained by combining the
flowcharts of Figs. 3 and 8. That is, when either the
determination of the exhaust pressure difference $\Delta P/GA$ (step
S128) or the determination of the exhaust temperature
difference ΔTHC (step S127) results in YES, steps S150, S152,
S131, S132, S134, and S136 are performed. Refer to Fig. 3 or
8 with regard to the other steps.

When $\Delta P/GA \geq Dp$ is satisfied (YES in step S128) or ΔTHC
$\geq Dth$ (YES in step S127) is satisfied, the ECU 70 determines
whether the number of times the determinations of steps S127
and S128 resulted in YES is less than or equal to the stop
determination number Np (step S150).

If the number of YES determinations is less than or
equal to Np (YES in step S150), the ECU 70 checks whether the
present step S150 resulted from the YES determination of S128
(step S152). If the present step S150 resulted from the YES
determination of step S128 (YES in step S152), the ECU 70
refers to the addition correction map MAPadd of Fig. 5 and
determines the addition correction amount PMadd corresponding
to the exhaust pressure difference $\Delta P/GA$ (step S132). If the
present step S150 resulted from the NO determination of step
S128 and the YES determination of step S127 (NO in step
S152), the ECU 70 refers to the addition correction map
MAPtad of Fig. 9 and determines the addition correction
amount PMadd corresponding to the exhaust temperature
difference ΔTHC (step S131).

The ECU 70 corrects the estimated accumulation amount
PMsm in accordance with expression 2 with the addition
correction amount PMadd (step S134). This increases the
estimated accumulation amount PMsm to approach or become
equal to the actual accumulation amount.

The ECU 70 switches from PM elimination heating to burn-up heating after correcting the estimated accumulation amount (step S136) and temporarily terminates this process. The burn-up heating eliminates the PM clogging the front surface of the NOx storage reduction catalyst 36a, burns up the large amount of accumulated PM in the filter 38a that is greater than the estimated accumulation amount PMsm, and gradually reduces the deviation between the estimate accumulation amount PMsm and the actual accumulation amount PMsm. Even if the estimated accumulation amount PMsm is deviated from the actual accumulation amount when starting burn-up heating, the estimated accumulation amount PMsm is less than or equal to the maximum value BUpm of the correction determination reference range, which is slightly greater than the termination determination value PMend. Thus, burn-up heating does not rapidly burn a large amount of PM, and the filter 38a is not overheated.

The pressure difference sensor 50, the intake air amount sensor 24, the first exhaust temperature sensor 44, and the second exhaust temperature sensor 46 serve as a difference detector. The ECU 70 executing the regeneration control (Figs. 10 and 11) in steps S122, S124, S125, S126, S128, S150, S152, S131, and S132 functions as a correction control section.

The third embodiment has the advantages described below.

(a) The advantages described in the first and second embodiments are obtained. In particular, in addition to the exhaust pressure difference ΔP/GA between the upstream and downstream sides of the filter 38a, the exhaust temperature difference ΔTHC between the upstream and downstream sides of the filter 38a is used. Thus, the difference between the

estimated accumulation amount PMsm and the actual
accumulation amount is minimized so that the accumulated PM
is appropriately eliminated. This reliably prevents rapid
burning of a large amount of PM.

A regeneration controller for an exhaust purification
apparatus of an internal combustion engine according to a
fourth embodiment of the present invention will now be
described.

In the fourth embodiment, referring to Fig. 12, a single
filter 138a having a base coated with a layer of NOx storage
reduction catalyst is used instead of the two catalytic
converters described in the first embodiment, namely, the
first catalytic converter and the second catalytic converter.
A pressure difference sensor 150 detects the pressure
difference ΔP between the upstream and downstream sides of
the filter 138a. A first exhaust temperature sensor 144
detects the temperature (exhaust temperature thci) of the
exhaust within the filter 138a. A second exhaust temperature
sensor 46, an air-fuel ratio sensor 48, a third catalytic
converter 40, and an oxidation catalyst 40a are identical to
the corresponding components in the first embodiment, and are
given the same reference numerals as those components.

The pressure difference sensor 150 detects the exhaust
pressure difference ΔP/GA between the upstream and downstream
sides of the exhaust purification apparatus. The first
exhaust temperature sensor 144 detects the temperature of the
exhaust in the filter 138a. The second exhaust temperature
sensor 46 detects the temperature of the exhaust in the
vicinity of the outlet of the filter 138a. Accordingly, the
first and second exhaust temperature sensors 144 and 46
detect the exhaust temperature difference ΔTHC(thco-thci) at

a relatively downstream portion of the exhaust purification apparatus.

The regeneration mode execution determination and the regeneration control described in one of the first to third embodiments are executed.

The fourth embodiment has the advantages described below.

(a) The catalyst arrangement according to the fourth embodiment also minimizes the difference between the estimated accumulation amount PMsm and the actual accumulation amount so that the accumulated PM is appropriately eliminated. This prevents a large amount of PM from being rapidly burned.

It should be apparent to those skilled in the art that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Particularly, it should be understood that the present invention may be embodied in the following forms.

(1) In the above embodiments, burn-up heating is performed when the determination relating to the exhaust pressure difference ΔP/GA or the determination relating to the exhaust temperature difference ΔTHC results in YES. However, normal PM elimination heating may be continued instead of switching to such special heating.

(2) The maximum value BUpm in the above embodiments may be the same value as the termination determination value PMend.

(3) In the above embodiments, the exhaust flow amount may be calculated from a driving state of the diesel engine 2, for example, from the engine speed NE and the fuel injection amount using a map instead of detecting the intake air amount GA using the intake air amount sensor 24. The ΔP/exhaust flow amount may be used as the exhaust pressure difference in various processing. Further, the correction reference value map MAPdp may be generated based on the exhaust flow amount.

The present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope and equivalence of the appended claims.